Technology Refresh of NOAA's Tropical Atmosphere Ocean (TAO) Buoy System

Chung-Chu Teng, Landry J. Bernard, Pete A. Lessing
NOAA National Data Buoy Center
1100 Balch Blvd.
Stennis Space Center, MS 39529 USA

***Abstract-* National Oceanic and Atmospheric Administration's (NOAA) Tropical Atmosphere Ocean (TAO) buoy array has a long history of providing valuable climate data to both the climate and forecast communities. A major concern for a sustained and long-term TAO operation is the impending obsolescence of the technology used in the current version of the TAO array. An increasing number of components are being discontinued or are no longer supported by the manufacturers due to the technology presently used being more than 10 years old. During the transition of the TAO array from NOAA's Pacific Marine Environmental Laboratory (PMEL) to NOAA's National Data Buoy Center (NDBC), it was decided to take this opportunity to "refresh" the TAO buoy system by replacing the obsolescent components in the current TAO system to ensure continuity of the TAO array. This paper first discusses the obsolescent components in the existing TAO array system. Then, the refreshed components of the refreshed TAO buoy system are discussed, including a newly-designed data logger, modified battery system, commercial off-the-shelf underwater sensors, a new compass, Iridium communication, modified and enhanced shore-side data system, and other minor design modifications. The field testing of the TAO refreshed buoys is also presented.**

I. INTRODUCTION

Development of the TAO buoy array was motivated by the 1982-1983 El Niño event. The event proved the need for real-time in-situ data from the tropical Pacific for monitoring, prediction, and improved understanding of El Niño. The success of the TAO array early in the international Tropical Ocean Global Atmosphere (TOGA) Research Programme led to widespread support within the climate research community. The entire TAO array was installed over a 10 year period and was completed in December 1994 by NOAA's Pacific Marine Environmental Laboratory (PMEL). By January 1, 2000, moorings west of 165 East were established with TRITON (Triangle Trans Ocean Buoy Network) buoys and maintained by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). In recognition of Japan's contribution, the array was re-named the TAO/TRITON array. Development, design, and testing of the TAO array were documented in References [1], [2], [3], and [4]. Figure 1 shows a location map of the TAO/TRITON buoy array, in which the blue squares represent the 55 TAO buoy sites, the yellow squares represent the 12 TRITON buoy sites, and the red squares represent the supplemental ocean current profile sites.

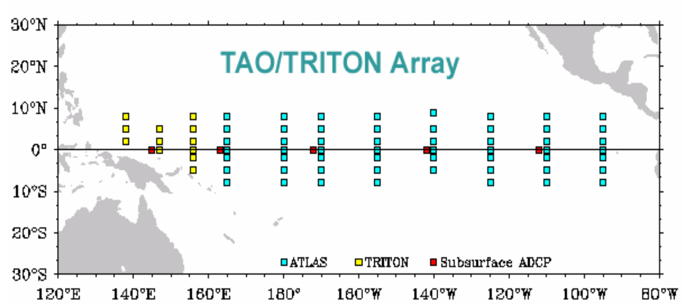

Figure 1. TAO/TRITON Buoy Array Locations

Because the TAO array is mature and providing valuable data to both the climate and forecast communities, NOAA decided the TAO array should be transitioned from NOAA research to NOAA operations. Thus, the operation and maintenance responsibility for the TAO Array is being transitioned from PMEL to the NOAA National Data Buoy Center (NDBC). The transition includes all operational aspects of the 55 TAO buoy sites and associated ancillary sites related to the TAO array.

During the TAO transition, a major concern of both NDBC and PMEL is the impending obsolescence of the technology used in the current version of the TAO array. As much of the existing technology is approaching 10 years of age, an increasing number of components are being discontinued or are no longer supported by manufacturers. To ensure ongoing continuity of the TAO array, it was decided to "refresh" the TAO system by replacing the obsolete components. The major refreshed components include the data logger, underwater conductivity/temperature (CT) sensors, and the compass for measurement of wind direction. Meanwhile, to increase the transmission frequency and transmitted data volume (without increasing the power consumption), it was decided to use the Iridium communication system for the refreshed TAO system so that detailed data could be transmitted to NDBC each hour in near real-time. Accordingly, the shore-side data system for data ingest, processing, quality assurance/quality control (QA/QC), and display also needed to be modified and enhanced.

As the refresh effort proceeds, refreshed sensors and components will be fully tested in the lab. Then, the refreshed TAO system, when fully instrumented, will operate alongside existing TAO buoys for an inter-comparison study. Upon

1-4244-0115-1/06/$20.00 ©2006 IEEE

Report Documentation Page

Form Approved OMB No. 0704-0188

1. REPORT DATE **01 SEP 2006**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Technology Refresh of NOAAs Tropical Atmosphere Ocean (TAO) Buoy System**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NOAA National Data Buoy Center 1100 Balch Blvd. Stennis Space Center, MS 39529 USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002006. Proceedings of the MTS/IEEE OCEANS 2006 Boston Conference and Exhibition Held in Boston, Massachusetts on September 15-21, 2006, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**6**	

completion of satisfactory inter-comparisons, the refreshed TAO systems will gradually replace the existing TAO components as funding for replacement hardware allows.

II. Needs for TAO Technology Refresh

Currently, a TAO buoy system consists of a subsurface array of eleven (11) sensors that measure conductivity and temperature (CT), temperature only (T), or temperature and depth (TP) at selected depths below the surface of the ocean, and a surface expression containing a variety of meteorological and climate measurement sensors. At flux reference sites, solar radiation sensors are installed on the surface expression, and subsurface current profilers are also installed. A typical TAO buoy/mooring is shown in Figure 2.

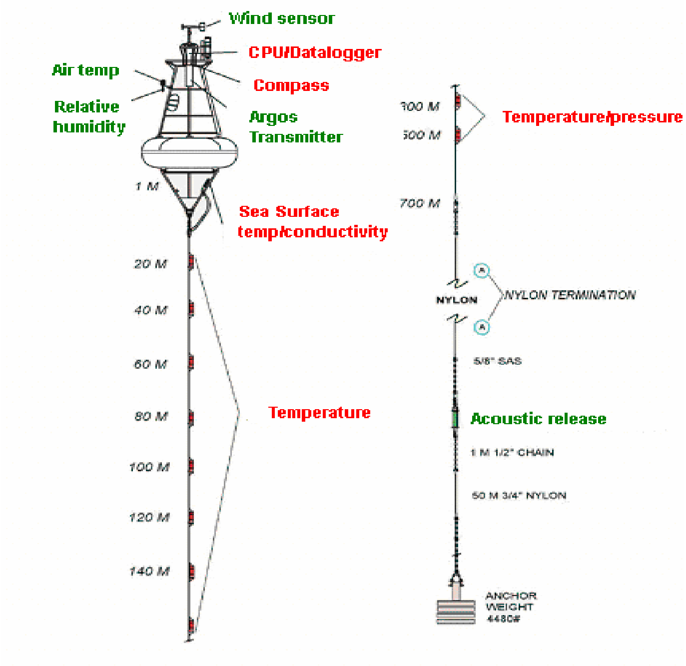

Figure 2. TAO Buoy and Mooring Configuration

The replacement of obsolete sensors and systems is part of the technology refresh plan for the TAO array that focuses specifically on known obsolete sensors and components. This will ensure continuity and serviceability of the TAO array. The obsolete components in the existing TAO buoy are described in the following.

These eleven T, CT, or TP underwater sensors use the same processor electronics for data collection and processing that employs a 68HC11 Programmable Interrupt Controller (PIC) microcontroller. The 68HC11, along with the supporting memory components, are obsolete and no longer manufactured. The operating system that drives the 68HC11 PIC is written in the FORTH programming language and cross-assembled to native code for the 68HC11. The inductive modem embedded in each underwater sensor that provides the telemetry link to the surface data logger through the mooring cable of the TAO buoy is also an obsolete design. It was decided that the most effective approach would be to replace these obsolete underwater sensors and inductive modems with commercial off-the-shelf (COTS) underwater sensors and inductive modems.

The data logger electronics, which interfaces to the surface sensors, the surface inductive modem, and data telemetry system, also has obsolete components. The data logger electronics employs a Motorola 68332 microprocessor. This microprocessor is a 5 VDC-powered component. The 68332 is now manufactured in only a 3.3VDC-powered version. The data logger also suffers from obsolete memory components and the operating system for it was also written in the FORTH programming language. Replacing the 68332 microprocessor and memory with lower voltage, supportable components or a COTS processor and memory will necessitate replacement of much of the interface logic on the data-logger board.

The TAO data-logger contains a surface inductive modem embedded in it which was designed and manufactured by PMEL and communicates with the subsurface sensors over the mooring cable. This surface inductive modem can be replaced by a COTS inductive modem subassembly.

One of the environmental sensors mounted on the TAO buoy superstructure measures wind velocity components. To measure wind velocity components, a magnetic compass is embedded within the data-logger to provide earth referenced coordinates for the wind velocity components. The compass embedded in the TAO data logger is a fluxgate compass originally manufactured by EG&G and since replaced by a KVH compass when the EG&G compass was discontinued. The KVH compass has also been discontinued by the manufacturer. TAO compass inventory is presently a mix of both EG&G and KVH compasses. Both compasses are no longer supported and need to be replaced.

The TAO flux reference sites include sensors that measure long-wave and short-wave solar radiation. The present solar radiation sensors incorporate signal conditioning circuitry designed by PMEL. In addition, some of the TAO sites include rain gauges for precipitation measurement that is reported as rain rate. These sensors contain custom, PMEL-designed signal conditioning and interface electronics. Because a new data logger is designed to replace the existing data logger, the conditioning and interface electronics for these sensors also needs to be redesigned.

III. Refreshed TAO Buoy System

A new data logger named the Advanced Modular Payload System (AMPS) was designed and developed for the TAO refreshed system and other NDBC programs [5]. The AMPS, which provides data acquisition, control, processing, and telemetry for a variety of operational environmental measurement programs, is an advanced data logging system that is modular, very low power, and small in size. It supports a variety of sensor input signals, sampling rates, averaging intervals, measurement resolutions, measurement ranges, and measurement accuracies. With the Graphic User Interface (GUI), the AMPS is easily configurable with user-friendly software that can be setup in the field. AMPS physical design has a cylindrical volume not exceeding 6 inches diameter by 9 inches length (full configuration). Figure 3 shows a photo of the prototype AMPS.

Figure 3. Prototype AMPS

The following are the key features of AMPS:

- A processor/controller with memory, data storage, digital I/O, time keeping, position, and serial communication ports.
- A 16 bit analog system with programmable sample rate input range.
- Necessary signal conditioning, power regulation, power conversion and power control components.
- Upgrade-ability through the use of expansion modules. Modules will allow for additional sensors and measurement systems to be added to the AMPS systems without hardware modification.
- Diagnostics that allows real-time display of all sensor inputs in either engineering units or the low level inputs.
- Built-in Test (BIT) for its operational state and the operational state of connected telemetry devices.

The AMPS hardware configuration can be divided into six systems; a main control board, power supply board, an analog board, a communications board, an optional serial board, and a patch panel board. Due to its modular design, it is easy to configure the boards or add/stack more boards (such as more serial or analog boards) for various measurement requirements or programs. Figure 4 shows a block diagram of the hardware of the AMPS for the TAO application, which includes the main control board, an analog board, the power supply board, and a communication board. All of these boards are connected to a patch panel.

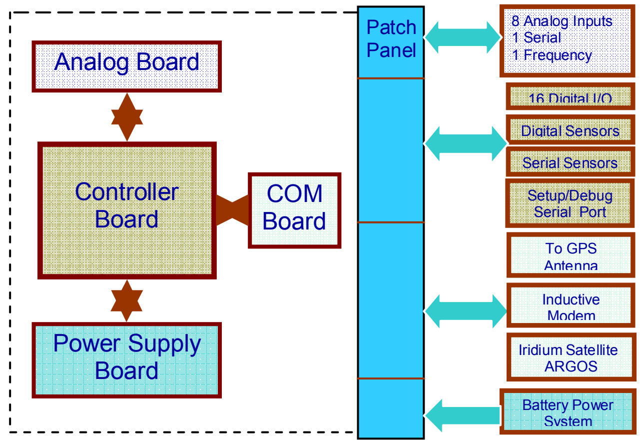

Figure 4. Block Diagram of AMPS TAO Configuration

The AMPS main or controller board, which utilizes an Atmel AT91RM9200 ARM 9 processor, connects to the SRAM, Flash, and SD card memory. This board also contains the spare digital I/O port.

The AMPS analog board, which utilizes an MSP430 microcontroller, controls the collecting of all analog data from sensors. In addition to collecting analog data the board will provide an interface for wind speed and compass inputs. The analog board will also allow for sensor inputs, which support digital Serial Peripheral Interface (SPI) and interface rain rate and long-wave and short-wave radiation sensors by RS-422. The analog board also supports data collection from a NMEA data format serial compass. TAO configuration requires internal compass measurement in support of wind direction calculations. AMPS uses the Sparton SP3000 internal compass, which has a power requirement of 8mA @ 3.3VDC and a heading accuracy of 0.3° and a resolution of 0.1°. AMPS supports up to three installed analog boards

AMPS power supply board provides power and power management/control for the AMPS system and sensors, which has an input power range of 6 - 18VDC. The AMPS communication board allows easy interfacing to AMPS serial communications devices, which include communications with inductive modem type devices thru a surface inductive modem (SIM). To reduce power consumption, a newly-designed low-power Seabird inductive modem module (IMM) was adopted for the AMPS data logger design, rather than the standard SIM now used. The communication board also uses an internal Trimble GPS receiver for accurate time keeping and position information. The AMPS serial board, which provides for up to 8 additional serial channels, allows for expansion of the AMPS to interface with serial devices. The patch panel board is the breakout panel that allows interaction with the AMPS in the form of external signals. The patch panel board also supplies power to some sensors and devices.

Data measured from AMPS can be transmitted and reported in real time by many means including GOES satellite, Iridium modem, Line-Of-Sight (LOS) RF radio, ARGOS, or cellular modem. In order to increase the transmission frequency and transmitted data volume (without increasing the overall power consumption), it was decided to use the short burst data (SBD) mode of the Iridium communication system as the primary communication for the refreshed TAO buoy system. The current TAO system uses the ARGOS communication system to transmit data, which has limited transmission length. That means only a few bulk parameters can be transmitted daily and detailed TAO data are stored in the buoy system (and can only be retrieved during buoy field services). With the Iridium communication system, all the detailed TAO data will be transmitted hourly in near-real-time, and the stored data will be used as backup only. The ARGOS system provides duplicate data transmissions approximately every two minutes for four hour periods twice a day, with up to 64 bytes of data per transmission depending on the number and type of sensors installed, that consists of hourly averages of TAO data. This transmission schedule provides for up to 8 of 24 possible hourly averages from a TAO buoy each day. The SBD Iridium system can provide the ten minute averages every hour in near real-time with up to 1960 bytes of data each transmission, without the duplicate transmissions as with ARGOS, thus providing nearly immediate access to all TAO high resolution data from which hourly and daily averages can be computed, all with less power consumption. In addition, the Iridium system provides for the capability of bilateral communication with the buoy for troubleshooting and diagnostics.

The AMPS software includes both firmware and GUI designs. The AMPS embedded software contains firmware developed for the ARM 9 using ANSI C compiled with IAR Systems Embedded Workbench and firmware developed for the MSP430 using ANSI C also compiled with IAR Systems Embedded Workbench. The GUI test and diagnostics software is developed for a Windows PC using National Instruments LabView 7.

Following development, design, and testing of the AMPS, NDBC integrated the AMPS with other existing and refreshed sensors in the TAO buoys. It was decided to (1) re-use the current TAO buoy hull, bridle, and mast design and (2) re-use the current electronic tube form factor. These were kept to take advantage of existing custom built racks and structures present on the primary TAO service vessels.

The existing electronic tube is 6-inches in diameter by 46.5-inches long. The upper part of the tube contains the AMPS data logger and the Iridium modem. The lower part houses the battery (power) pack (as shown in Figure 5). Presently, D size alkaline batteries are used for TAO systems. Lithium battery packs will be considered for future deployments. The power pack, which has a tubular design, is electrically arranged in two banks: one for AMPS and one for the Iridium Modem. All wires route to a diode board, which provides isolation of strings and parallel wiring of strings of batteries. From the diode board, two plugs plug into the AMPS (1 for AMPS and one for switched power to Iridium modem). Batteries are contained in an acrylic vented container. An insulator plate, which exists between layers, supports the weight of batteries. Space for 10 layers of 14 D size batteries. The inputs range for both AMPS and the modem is 6 to 15 VDC. One string of 7 batteries provides 10.5 VDC. The tube has a capacity for 20 strings: 14 strings for the AMPS and 6 strings for the Iridium modem. Based on the estimated average load 0.192 AHRS/Day for AMPS and 0.062 AHRS/Day for the modem, the system has more than 500 days of operational life. Of course, actual life and performance will need to be measured through testing.

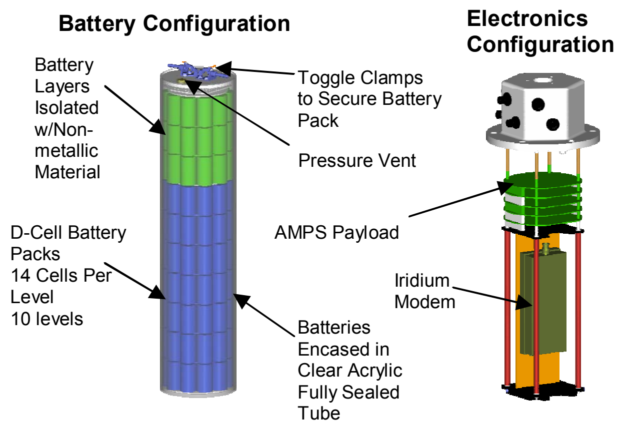

Figure 5. AMPS Electronic and Battery Configurations in TAO Tube

As discussed in the previous section, COTS conductivity/temperature/depth (CTD) sensors are used for the refreshed TAO system to replace the current custom subsurface sensors. The refreshed TAO system is designed to use the inductive modem (IM) CTD sensors manufactured by Seabird. The specifications of these COTS sensors meet or exceed the accuracy requirements published for the TAO network. Currently, JAMSTEC is using the same COTS sensors in its TRITON buoy array. Depending on applications, T, CT, TP, and CTD sensors can be mounted at specified locations along the wire rope which serves as the communication path for the inductive communication. The AMPS data logger is designed with the capability for handling inductive modem communication.

The conditioning and interface electronics for the rain gauge and radiation sensors need to be redesigned for the new data logger. Custom electronics are designed to digitize sensor signals to produce engineering units needed for the RM Young rain gauge (Siphon type model 50202) and both short-wave and long-wave Eppley radiation sensors (Eppley Labs Models PSP and PIR). Communications between the sensor host controllers and AMPS payload are RS-422.

Compared to limited data transmitted daily from the current ARGOS system, the detailed data collected by AMPS is transmitted hourly from the Iridium SBD system used for the refreshed TAO buoy system. Thus, the shore side data system has to be modified for the much larger data volume in near real time and more frequent data transmission of the refreshed TAO system and to compute the hourly and daily average products now provided from the TAO array.

Currently, the TAO data system contains five sub-systems: (1) Real-time Processing (using current TAO payload and Service Argos), (2) Data Monitoring and QA/QC (on Daily/Hourly Data only), (3) Calibration/Inventory (using flat files only), (4) Web Data Display and Delivery (with advanced plotting), and (5) Delayed Mode Processing (performing post-calibration/correction). These five subsystems are being modified and enhanced for the refreshed TAO system.

1) Real-time Processing: With the hourly data from the Iridium and the new AMPS format, this subsystem will be significantly modified and enhanced.
2) Data Monitoring and QA/QC: This subsystem is modified for detailed high resolution data.
3) Calibration/Inventory: This subsystem will be enhanced to include sensor and data management database system which will interface with NDBC's inventory system.
4) Web Data Display and Delivery: This subsystem will be enhanced to handle parallel comparison for co-located current and refreshed TAO buoys.
5) Delayed Mode Processing: Because most of the delayed mode data will be transmitted back in real time, this subsystem will be re-structured.

Figure 6 presents a block diagram of the data system for the refreshed TAO system. This data system includes four components: (1) Ingest system, (2) Real-time processing, (3) Sensor management, and (4) Web display. These components all connect to a centralized sensor/data management database (i.e., the oval box at the center of the figure) [6].

The ingest system has certain ports open to receive Iridium data and to support partners/users via FTP. Data transfer and storage capabilities are at the NWSTG at Silver Spring with the failover capabilities, in case of a catastrophe or downtime, to a backup server at NDBC at Stennis Space Center from a router or global load balancer (GLB). The system at NWSTG is accessible through NOAANet for remote management and software upgrades from NDBC.

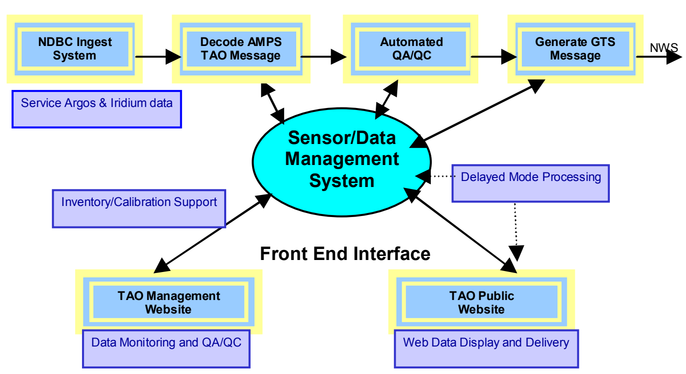

Figure 6. Data System for TAO Refreshed System

The real-time processing system retrieves data from the ingest system and provides three independent processing queues: decoding TAO message, automated data QA/QC checks, and GTS message generation. The high resolution real-time data from the refreshed TAO system will be decoded and stored in a database. Various QA/QC checks are performed on incoming decoded data in the database. Then, the GTS message is generated and sent to GTS. For TAO messages, FM-18 is the primary GTS format. Other formats, such as FM-64 and FM-13 may be considered in the future.

For the sensor management system, a shore-side sensor database will be established to manage sensor information, which will interface with existing NDBC inventory system, support sensor tracking, and support buoy system integration. An offshore sensor database, which is spawned from the shore-side sensor database, allows ship deployment personnel to track sensor modifications during retrieval/deployment operations and support remote synchronization with in-house sensor data system. At NDBC, personnel at the Data Assembly Center (DAC) will provide support of sensor configuration and update.

The web display system will provide capability to deliver near real-time 10-minute data from refreshed TAO buoys. Both the current and refreshed TAO buoy sites will be integrated into the web display. The plots will be generated using netCDF files dynamically by extracting data from the database.

At NDBC, the DAC provides a 24x7 operation to monitor the data flow and quality. The DAC personnel will support various data plotting, data flag assignments (quality flags and release flags), updates on TAO Website with real-time released data, and data archive in 291 Format.

IV. Field Testing of the Refreshed System

After lab testing, a prototype refreshed TAO test buoy was integrated and tested at NDBC. The buoy is being deployed and serviced in the Gulf of Mexico at the time this paper is being written. This test buoy is located at 28° 54' 53" N 088° 15' 59" W (Station ID 42070) with a water depth of 1189m (3900ft), which is 16 nm South of Station 42040. Data from this buoy will be carefully analyzed to evaluate the performance of the refreshed TAO system, and the results will be published in a separate paper in the near future.

This test buoy is equipped with an air temp/humidity sensor (Rotronics MP101A), an anemometer (RM Young 5103), a sea surface conductivity/temperature sensor (Seabird model 37SM) on the bridle, 5 subsurface temperature (T) sensors (Seabird 39IM) on the IM line, 3 subsurface temperature and conductivity sensors (Seabird 37IM), and 2 temperature and pressure sensors (Seabird 39IM).

The mooring for this prototype TAO refreshed buoy is the same as the taut mooring design (as shown in Figure 7) which uses 3/8" Jacketed galvanized steel wire on the top part as the inductive modem line and 3/4" Nylon rope for the remaining of the mooring. To reduce cost, we use a cement clump instead of railroad wheels as anchors for this test. An acoustic release (ORE Offshore 8242XS) is also installed for easy retrieval of the mooring and attached underwater sensors. Because the water depth of this test site is significantly shallower than the standard TAO sites, the locations/spacing of the underwater T/CT/TP sensors (as shown in Figure 7) are different from the standard configuration for standard TAO buoys (such as that shown in Figure 2).

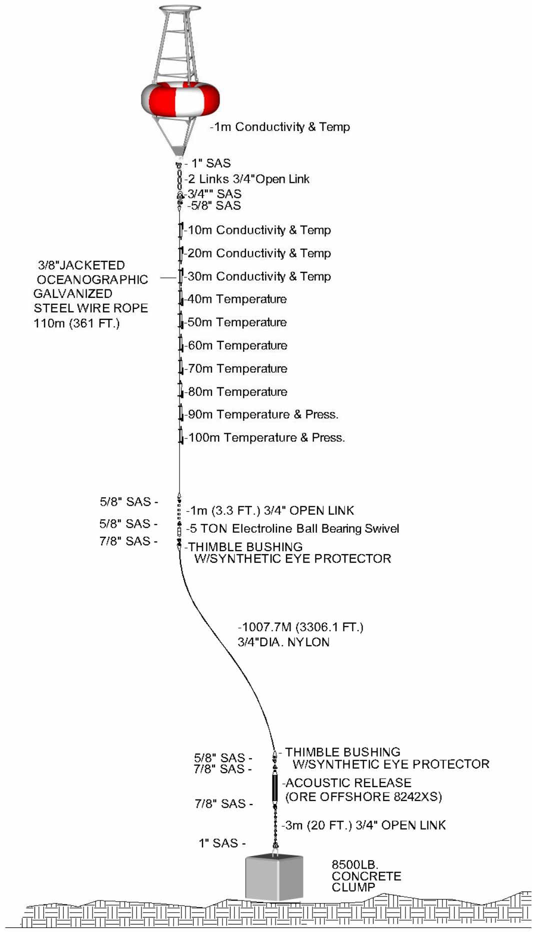

Figure 7. Mooring and subsurface sensor configuration for prototype refreshed TAO buoy deployed at Gulf of Mexico

Currently, two more refreshed TAO buoys are being integrated and tested at NDBC for inter-comparison testing in accordance with requirements and guidelines published by NOAA and forecast and climate communities [7]. It is planned to deploy these two refreshed buoys next to two existing TAO buoys at 5N 110W and 0 110W (which is a flux reference site) during the planned service cruise in March 2007. Both refreshed TAO buoys will be equipped with the standard TAO sensors, including the standard met sensors (one wind sensor and one air temperature/relative humidity sensor), a sea surface conductivity sensor, and 10 underwater temperature sensors (at the standard TAO subsurface sensor locations along the mooring, such as those shown in Figure 2). The buoy at the flux site will have more sensors and measurements, including four subsurface conductivity measurements (combined with the temperature measurements at the upper four sensor locations), four point-source current meters (near the upper four sensor locations), a barometer, a rain gauge, a short-wave radiation sensor, and a long-wave radiation sensor.

Upon completion of satisfactory inter-comparison tests, the refreshed TAO systems will replace the existing TAO components as funding for replacement hardware allows.

V. Concluding Remarks

Development and deployment of the TAO refreshed system is aimed toward the most important TAO transition principle as stated in the TAO Transition Plan [8]: "Lay the groundwork for sustained and successful TAO operation after the transition." As stated in this paper, the refreshed TAO system is intended to ensure continuous operation and ongoing integrity of the TAO array. For the purpose of a sustained and long term TAO operations, PMEL and NDBC will work together to develop, test, and deploy the next-generation TAO system.

When developing and implementing the TAO refreshed system, NDBC always keep two other major transition principles in mind: "Maintain the quality and integrity of the data" and "Ensure transparency of the transition to current TAO data users and partners". During the system modification and enhancement, NDBC will maintain the continuity of TAO field operations, system performance, data quality, and data display and delivery of the TAO buoy array. NDBC believes, before and after the technology refresh of the TAO array is completed, there will be a sustained, smooth, and continuous TAO system which can continuously provide high quality climate data to various users in scientific, climate, and forecast communities.

Acknowledgement

The authors would like to thank engineering, IT, and operational staff from the Neptune Sciences Division of Planning Systems, Inc. and Science Applications International Corporation (NDBC's Technical Service Contractor) for their technical and operational contribution to this project. Support from PMEL's TAO office and engineering/IT staff is also greatly appreciated for a successful TAO transition and TAO technology refresh.

Reference

[1] M.J. McPhaden, "The Tropical Atmosphere Ocean array is completed," *Bull. Am. Meteorol. Soc.*, vol. 76, no. 5, pp. 739-741, May 1995.

[2] H. P. Freitag, Y. Feng, L. J. Mangum, M. J. McPhaden, J. Neander, L. D. Stratton, "Calibration Procedures and Instrumental Accuracy Estimates of TAO Temperature, Relative Humidity and Radiation Measurements**"**, Contribution No. 1589 from NOAA/Pacific Marine Environmental Laboratory, December 1994.National Data Buoy Center (2006), "IT Refreshed TAO Requirements", NDBC Report, April 26, 2006.

[3] H.B. Milburn, P.D. McLain, and C. Meinig, "ATLAS Buoy - Reengineered for the Next Decade", Proceedings of IEEE / MTS Oceans '96, 698-702, 1996

[4] H.B. Milburn and P.D. McLain, "ATLAS--A low cost satellite data telemetry mooring developed for NOAA's Climate Research Mission," Proceedings from MTS Marine Data Systems, New Orleans, 1986.

[5] Planning Systems, Inc., "Advanced Modular Payload System (AMPS) – System User Manual", Technical report submitted to NDBC, April 2006.

[6] National Data Buoy Center, "IT Refreshed TAO Requirements", NDBC Report, April 26, 2006.

[7] National Data Buoy Center, "Requirement Assessment Project for the Tropical Atmosphere Ocean (TAO) Operational System Refresh (TAO Refresh)," NDBC Report, July 2006.

[8] National Data Buoy Center and Pacific Marine Environmental Laboratory, "TAO Transition Plan", August 2004.